

FINAL REPORT

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EXPERIMENTAL STUDY OF LUNAR AND SNC MAGMAS

P.I. Malcolm J Rutherford  
Geological Sciences Department,  
Brown University, Providence R.I.

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PROJECT SUMMARY

**1. General** The research described in this progress report involved the study of petrological, geochemical and volcanic processes that occur on the Moon and the SNC parent body, generally accepted to be Mars. The link between these studies is that they focus on two terrestrial-type parent bodies somewhat smaller than earth, and the fact that they focus on the role of volatiles in magmatic processes and on processes of magma evolution on these planets.

The work on the lunar volcanic glasses has resulted in some exciting new discoveries over the years of this grant. During the tenure of the present grant, we discovered a variety of metal blebs in the A17 orange glass. Some of these Fe-Ni metal blebs occur in the glass; others were found in olivine phenocrysts which we find make up about 2 vol % of the orange glass magma. The importance of these metal spheres is that they fix the oxidation state of the parent magma during the eruption, and also indicate changes during the eruption (Weitz et al., 1997). They also yield important information about the composition of the gas phase present, the gas which drove the lunar fire-fountaining. In an Undergraduate senior thesis project, Nora Klein discovered a melt inclusion that remained in a glassy state in one of the olivine phenocrysts. Analyses of this inclusion gave additional information on the CO<sub>2</sub>, CO and S contents of the orange glass magma prior to its reaching the lunar surface. The composition of lunar volcanic gases has long been one of the puzzles of lunar magmatic processes.

One of the more exciting findings in our research over the past year has been the study of magmatic processes linking the SNC meteorite source magma composition with the andesitic composition rocks found at the Pathfinder site. In this project, graduate student Michelle showed that there was a clear petrologic link between these two magma types via fractional removal of crystals from the SNC parent melt, but the process only worked if there was at least 1 wt % dissolved water in the melt (Minitti and Rutherford, 2000).

## **2. Progress on specific projects**

### **a) Picritic Lunar Glasses, Volcanism, Volatiles, and Lunar Oxidation State**

Primitive picritic lunar glasses, such as the Apollo 15 green and the Apollo 17 orange glasses, are widely considered to be the products of volcanic fire-fountaining in the lunar mare. Although the "fire-fountain theory" appears to be the most plausible explanation for the formation of primitive lunar glasses, many basic elements regarding their genesis and significance remain unknown. Among these are: 1) The volatiles present in the primitive lunar melts, 2) The composition of the evolved volcanic gas phase, 3) The amount of melt degassing, the depth at which it occurs, and its effect on the oxidation state of the glasses, 4) The physical processes involved and the timing of the different eruption phases.

During the tenure of the present research grant, we have further studied the core samples taken through the orange glass deposit at the A1& lunar site. Dr. Cathy Weitz did research on these samples and together with the P.I. wrote and published two papers describing and interpreting their mineralogy and composition. One of these papers was on the metal spherules we discovered in the orange glass samples; the results indicated this magma became saturated with a C-O gas at about 4 Km depth as it ascended to the lunar surface. The development of this gas phase caused a reduction of silicate iron to form the metal spherules in the basaltic melt, and some were trapped in growing olivine phenocrysts. In the second paper Dr. Weitz correlated the conditions determined from the metal spherules with those indicated by Spinel crystals also trapped in the orange glass olivine phenocrysts.

b. The KREEP-QMD-Granite association on the Moon:

A project to experimentally determine the relationships between KREEP basalt, quartz monzodiorite (QMD), and lunar granites has been completed and the manuscript is essentially written. The problems studied are the following. The lunar sample suite contains some pristine KREEP basalt samples such as those found at the Apollo 15 site, as well as those at A14 and A17. Associated with KREEP are intermediate composition (based on major elements) samples of QMD with very high REE abundances, and the lunar granites. We have worked to determine the possible petrogenetic relationships between these rocks. We have now determined that a composition such as A15 KREEP basalt fractionates along a path at 3 kb that is similar to the 1 atm fractionation, but the miscibility gap (SLI) also expands to higher temperatures with increasing pressure (Rutherford et al., 1996). This expansion is such that SLI develops when the SiO<sub>2</sub> content of the residual melt is no more than 52-53 wt % compared to 54-55 % at 1 atm. This means that lunar granites formed at depth are almost certainly produced by silicate liquid immiscibility, and that intermediate composition magmas such as QMD become more difficult to produce at depth.

c. SNC "Mars" Meteorite Studies

The SNC meteorites and the role of volatiles in SNC magmatic processes is another problem we have continued to study. To review, geological evidence strongly suggests the presence of significant H<sub>2</sub>O abundances on Mars throughout its history, and petrological studies identified kaersutitic hornblende + biotite inside melt inclusions in many of the SNC meteorites. On the other hand, little evidence of water exists in the SNC meteorites outside of the phenocrysts; few hydrous minerals are present and the impact glasses contain only traces of H<sub>2</sub>O.

In our most recent study of these problems, graduate student Michelle Minitti and the P.I. have studied the crystallization of a basaltic melt composition like the one which would have

crystallized the SNC meteorite now accepted as having come from Mars. In this study we determined that a more evolved melt equivalent in composition to the rocks analyzed at the Pathfinder site on Mars could be produced from the SNC starting melt. The process required is removal of early formed crystals, but the data clearly showed that the original SNC basaltic composition melt would only produce the Pathfinder Andesite if there was at least 1 wt % water dissolved in the melt. Thus, these experiments appear to add further to the evidence that suggests there was significant water on Mars, not only on the surface but in the Mars interior.

## **PUBLICATIONS AND THESES**

### Published and Submitted Papers:

- Weitz, C.M., Rutherford, M.J., and Head, J.W., 1997, Oxidation States and ascent history of the Apollo 17 volcanic beads as inferred from metal-glass equilibria. *Geochimica Cosmochimica Acta*, 61, p. 2765-75.
- Weitz, C. M., M. J. Rutherford, Head, J.W., and McKay, D.S., (1999) Ascent and Eruption of a Lunar High-Ti magma as inferred from the Petrology of the 74001/2 Drill Core. *Meteorites and Planets*, 34, 527-540 .
- Minitti, M.E., and Rutherford, M.J. (2000) Genesis of the Pathfinder "sulfur-free" rock from SNC parental liquids. *Geochimica Cosmochimica Acta*, 64, .
- Rutherford, MJ, and Holmberg, B., (submitted) Experimental study of A15 KREEP basalt: constraints on origin and evolution of KREEP and related rocks. *J.G.R.*

### Abstracts of papers presented at meetings

- Minitti, M., Rutherford, M.J., Giletti, B.J., and Schultz, P.S., 1997, The effects of Impact on D/H in hornblendes: Application to SNC Petrogenesis. *LPSC XXVIII*, p.959-60.
- Rutherford M.J. and Weitz, C.M., 1997, Oxidation State of the A17 orange glass source as inferred from Inclusions in olivine phenocrysts. *LPSC XXVIII*, p. 1211-12.
- Minitti, ME, Rutherford, MJ, 1998, The effects of Impact on D/H of hornblendes: applications to SNC petrogenesis. *LPSC XXIX*, p. 945-47.
- Klein N and Rutherford M.J. 1998, Pre-eruption volcanic Gas of Orange Glass magma: Evidence from glassy melt inclusions. *LPSC XXIX*, 570-72.
- Minitti M, and Rutherford M.J. 1999, Genesis of the Mars Pathfinder S-free rock from a SNC parent magma. *LPSC XXX*, 1198.
- Minitti, M and Rutherford, M.J. (1999) Genesis of the Mars Pathfinder "sulfur-free" rock from SNC parental liquids. *Abst. Proc. 5th Mars Conference*
- Weitz, C.M., and Rutherford, M.J. (1999) Some petrological explanations for the Magnetic anomalies detected on Mars. *Proc 5th Mars Conf.*

### Two PhD theses or parts of them were supported by this research grant

1. Catherine Weitz. PhD from Brown University in 1998. Thesis "Lunar Pyroclastic deposits and Effusive Constructs: Petrology, Eruption Styles, and Spectral Properties".
2. Michelle Minitti. PhD. anticipated from Brown University in Sept. 2000. Thesis "Investigations of the Effects of Impact Shock, Water and Oxidation on SNC (Martian) Meteorites, Magma Petrogenesis and Spectral Properties".

### One Undergraduate BSc thesis was supported by this research grant.

1. Nora Klein BSc 1998. Thesis entitled "Composition of gases in the Primitive Lunar Volcanic eruption of the A17 Orange glass magma from melt Inclusion data".